The Institute of Physics

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Notices to Members

Proceedings of the Thirty-sixth Annual General Meeting

The Thirty-sixth Annual General Meeting of the Institute was held on July 16, at 5 p.m. at the Institute's House. Professor F. A. Vick (*Vice-President*) was in the Chair. A quorum being present, the Secretary read the notice convening the meeting. The Minutes of the previous Annual General Meeting held on May 17, 1955, and of the Extraordinary General Meeting held on October 4, 1955, were read and approved and were then signed by the Chairman.

Mr. D. M. Smith (*Fellow*), Mr. J. R. Stansfield (*Associate*) and Mr. J. O. C. Vick (*Associate*) were appointed scrutineers of the ballot for election to the Board and for the election to Honorary Fellowship.

On the proposal of Dr. J. S. Forrest (*Fellow*), seconded by Dr. R. W. Sillars (*Fellow*) it was unanimously resolved that the accounts and balance sheets for the year ending December 31, 1955, be adopted. Dr. B. P. Dudding (*Honorary Secretary*) moved the adoption of the report of the Board for 1955 and this was seconded by Mr. H. P. Rooksby (*Fellow*). The resolution was carried unanimously.

Having received the report of the scrutineers the Chairman declared the following to be elected to fill the vacancies on the Board which will occur on September 30, 1956 :

President :	Mr. O. W. Humphreys
Vice-President :	Dr. B. P. Dudding.
Honorary Treasurer :	Dr. J. Taylor.
Honorary Secretary :	Professor F. A. Vick.
Ordinary Members of the Board :	Dr. L. R. G. Treloar and Mr. G. W. Warren.

In the ballot for the election of two Ordinary Members, 634 valid ballot papers were received. The voting was as follows :

Dr. L. R. G. Treloar	...	490
Mr. G. W. Warren	...	396
Mr. M. Milbourn	...	381

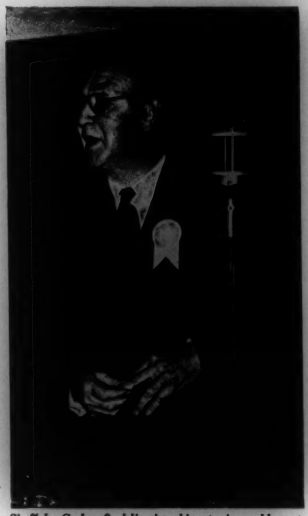
The Chairman declared that Sir George Thomson had been elected an Honorary Fellow of the Institute.

Messrs. Knox, Cropper and Co., were elected auditors for the year 1956.

Votes of thanks were moved to the President, Honorary Officers and members of the Board, the Honorary Officers of Branches and Groups and the bodies which have allowed the use of their rooms during the year for meetings. These were carried with applause.

Conference on " The Physics of Nuclear Reactors," London, July 3–6, 1956

The purpose of the Conference was to keep members of the Institute and its sister Institutions abreast of scientific developments in nuclear reactors and to call their attention to the problems needing solution. It was not intended to be the occasion for the announcement of important contributions to the subject and only limited time was provided for discussion in the sessions. The consequent ample time available for private discussion between sessions was greatly appreciated and remarked upon by many who attended.



Sir John Cockcroft delivering his opening address to the Conference on Nuclear Reactors.

In order to avoid overcrowding, the organizing Committee decided not to publicize the Conference in advance, and placed a strict limit on the number of foreigners from each country that would be allowed to participate. The endeavour was to limit the

At the press conference. Left to right : Dr. J. R. Dietrich (U.S.A.), Dr. G. C. Laurence (Canada), Dr. H. R. Lang, Sir John Cockcroft, and Mr. A. K. Krasin (U.S.S.R.).

total attendance to 500 or a little over. Non-members of the Institute were charged a Conference fee of two guineas, but members of constituent bodies of the British Nuclear Energy Conference were, in accordance with the constitution of the body, allowed to attend without charge. The Board also extended this concession to members of The Physical Society on this occasion.

The analysis of the attendance was :

Members of The Institute of Physics	214
Members of other constituent bodies of B.N.E.C.	116
Members of The Physical Society only	36
Others	108
	474

In addition to the United Kingdom, the following twenty-four countries were officially or unofficially represented at the Conference by a total of sixty-five persons (included in the total of 474) :

Australia	Austria
Belgium	Canada
Denmark	Eire
Egypt	Finland
France	Western Germany
Eastern Germany	Gold Coast
Holland	Israel
Italy	Malaya
Norway	India
Pakistan	Rhodesia and Nyasaland
Sweden	Switzerland
U.S.A.	U.S.S.R.

With the assistance of the Press Office of the Atomic Energy Authority, a press conference was arranged on the opening day and was presided over by the President. Some of the overseas representatives attended. About fifty press representatives attended. Unfortunately, the half-hour allowed was not long enough. Reference was made to the Conference in some of the principal National Dailies and by the B.B.C. (sound and television) and considerable attention is being given to it in the technical press.

The papers and lectures (other than Professor Peierls') will be published as a Supplement to the *British Journal of Applied Physics* before the end of this year.

Joint Conference—Stress Analysis Group and the Royal Aeronautical Society

Members are reminded that the Institute's Stress Analysis Group and the Royal Aeronautical Society have arranged a joint conference which is to be held at the College of Aeronautics, Cranfield, from the morning of September 19 to the afternoon of September 21. Residential accommodation is available, including a limited amount for the night of the 18th. Members who are not members of the Stress Analysis Group but who would like to have the details of the conference should apply to the Deputy Secretary. Early booking of accommodation is essential.

CORRECTION

In the article which appeared on p. 148 of the June issue, left-hand column, the reference to the development of the Ace and Deuce Computors should have read "resulting from the work of the National Physical Laboratory, Mathematics Division and the English Electric Co. Ltd."

Nuclear Reactors and the Economic Production of Nuclear Power*

By P. W. MUMMERY, M.A.

(*Atomic Energy Research Establishment, Harwell*)

SOURCE OF NUCLEAR ENERGY

UNTIL the advent of the "nuclear age," perhaps known more widely as the "atomic age," the sources of energy controlled by man were largely chemical in nature. The investigations of many scientists, in particular physicists and chemists, has shown that the fundamental laws governing the release of chemical energy can be best understood in terms of our knowledge of the atomic structure of matter and the concepts of equivalence of mass and energy and the conservation of energy.

All matter can be considered as composed of atoms which can be imagined to consist of a miniature solar system in which the sun is represented by the positively charged nucleus of the atom and the planets are represented by negatively charged electrons. The energy released in chemical reactions is then attributed to the redistribution of energy following upon a rearrangement of these electrons. In order to consider the amounts of energy involved in such processes it is convenient to introduce a microscopic unit of energy, the electron volt. This unit is the amount of energy acquired by a single negatively charged electron when accelerated by a potential difference of 1 volt, and it is equivalent to $1{\cdot}6 \times 10^{-19}$ watt secs., i.e. $4{\cdot}4 \times 10^{-26}$ kWh. Since the amount of energy associated with an electron in an atom is measured in units of electron volts (eV), this is a measure of the magnitude of any energy release associated with a chemical reaction.

A detailed study of the nucleus of the atom has shown that this is composed of more fundamental particles, protons and neutrons, and that the amount of energy associated with these particles is measured in units of millions of electron volts (MeV). Furthermore, it is known that very light and very heavy nuclei are not the most economical in their use of energy and if processes could be found whereby they could be converted easily to medium weight nuclei, a considerable release of energy could be obtained. The discovery of fission in 1939 by Hahn and Strassman provides a process by which very heavy nuclei can be broken into medium weight nuclei together with the release of about 200 MeV of energy. Of great practical importance is the fact that this process is caused by bombardment by neutrons and the fission process produces further neutrons thereby giving the possibility of a chain reaction whereby the number of nuclei fissioned can be increased at will.

It is believed that the source of energy in the sun is a process of fusion of light nuclei into the medium weight nuclei similarly releasing energy. This fusion process is the basis of the hydrogen bomb as the fission process is the basis of the atomic bomb. The release of appreciable quantities of energy by such processes still requires many nuclei as is indicated by the fact that a rate of energy release of 1 kilowatt requires 3×10^{16} fissions per second. Nevertheless there is a gain of a factor of the order of 10^6 in the amount of energy which can be released by nuclear reactions, compared with chemical reactions. For example, 10% utilization of 1 ton of nuclear fuel will give the same amount of energy as 300,000 tons of coal at its present level of utilization.

* Based on two lectures given to the Yorkshire Branch of the Institute on November 30, 1955

ESTABLISHMENT OF A CHAIN REACTION

The early development of nuclear reactors was associated with the use of naturally occurring uranium as the source of energy and a discussion of the uses of this material will illustrate the problems associated with the design of nuclear reactors.

Consider first the requirement that a chain reaction can be established. The ammunition in this process is a neutron so we must consider the conditions under which the number of neutrons present inside a reactor remains constant. This is a simple continuity condition.

$$\textit{Yield of neutrons} = \textit{Absorption of neutrons} + \textit{Leakage of neutrons} \quad \ldots \quad (1)$$

Neutrons can cause a variety of reactions in addition to fission; for example the emission of protons, alpha particles, gamma radiation or more neutrons. For a finite size of reactor neutrons will escape from the surface of the reactor. The concept of critical size of a reactor is simply that size at which the loss of neutrons from the surface is sufficiently small for a chain reaction to be established. It is convenient to rewrite equation (1) in a slightly different form;

$$\frac{\textit{Yield of neutrons}}{\textit{Absorption of neutrons in fissile material}} = \frac{\textit{Absorption of neutrons in all materials} + \textit{leakage}}{\textit{Absorption of neutrons in fissile material}}$$

$$= 1 + \frac{\textit{Absorption of neutrons in non-fissile material} + \textit{leakage}}{\textit{Absorption of neutrons in fissile material}} \quad \ldots \quad \ldots \quad (2)$$

In symbols we can say $\Upsilon = 1 + A + L$ (3)

It is immediately obvious that for a chain reaction in a finite reactor to be possible Y must be greater than unity.

THE NATURAL URANIUM REACTOR

Now natural uranium contains two isotopes in significant amounts, U^{238} and U^{235}, their abundances being in the ratio of 139 to 1. Furthermore the U^{238} nucleus is fissionable only by neutrons whose energy exceeds about 1 MeV, but the U^{235} nucleus is fissionable by neutrons of all energies. The neutrons emitted as a result of fission are distributed around a mean energy of about 2 MeV. The design problem with natural uranium therefore is to arrange that the reactor contains neutrons with an energy distribution which will give a sufficiently high value of Y. It is conventional to consider U^{235} as the only fissionable material present since, as will be discussed later, U^{238} is mainly of interest as a fertile material, i.e. one which on capture of a neutron will produce more fissionable material, i.e. Pu^{239}. The additional neutrons arising from U^{238} fissions are few in number since the processes of radiative capture and inelastic scattering of neutrons, the latter reducing the neutron energy below that at which fission can occur, are more likely than the process of fission.

The predominant effects are then :—

U^{235} neutron capture to give U^{236}

U^{235} neutron capture causing fission

U^{238} neutron capture to give U^{239} which decays to Np^{239} and then to Pu^{239}.

TABLE I

Neutron Energy	*Low (Thermal)*	*Medium (Intermediate)*	*High (Fast)*
U^{235} Yield Υ*	2·0	1·8	2·4
U^{235} Absorption	1·0	1·0	1·0
Spare $(\Upsilon - 1)$	1·0	0·8	1·4
U^{238} Absorption A_8	$\frac{139\sigma^{238}}{\sigma^{235}}$	$\frac{139\sigma^{238}}{\sigma^{235}}$	$\frac{139\sigma^{238}}{\sigma^{235}}$

* This can be enhanced by up to about 10% due to high energy fissions in U^{238}.

σ represents the absorption cross-section of a particular nucleus, i.e. the effective cross-sectional area presented to the neutron for the particular process (absorption) considered.

Now we see from Table I that the ratio $\frac{\sigma^{238}}{\sigma^{235}}$ must not exceed a certain value or the chain reaction cannot be sustained in a finite reactor. It turns out that it is possible only in a " thermal " reactor so to arrange the uranium that this value is not exceeded. By " thermal " neutron energy we mean a distribution of energies similar to that required by the macroscopic temperature of the materials in the reactor. In fact $A_8 < 1{\cdot}0$ is possible in a thermal reactor but $A_8 \sim 10$ in the other reactors.

Since the neutrons emitted at fission have a mean energy of about 2 MeV but we require the mean energy in the reactor to be due to " thermal " energies, i.e. 1/40 eV at 20°C., additional material is required in the reactor to slow down the neutrons without absorbing them. A good slowing down material, called a moderator, must have a low atomic number so that the mass of the nucleus is not too large by comparison with that of the neutron. Under these conditions the neutron shares a considerable fraction of energy with the other nucleus in a collision and so is rapidly reduced in energy. Common materials which have this property are water (H_2O) and graphite (C), but the former absorbs just too many neutrons for a practical reactor to be built containing natural uranium. Heavy water (D_2O) and beryllium or beryllia (Be, BeO) are more exotic materials which will suffice. Liquid helium or the separated isotopes Li^7 and B^{11} could also be used as moderators in principle.

With the uranium uniformly mixed with the moderator it is still difficult to obtain a chain reaction and the reason is that during the slowing down process the U^{238} can still capture too many neutrons. However, this capture is a result of many resonances in U^{238}, i.e. the absorption cross-section is very high over certain small energy ranges, a phenomenon analogous to the resonance absorption of light in various media. It is possible by lumping the uranium to introduce a self-screening factor which applies only to the U^{238} and not to the U^{235}. By this means the neutron absorption in U^{238} relative to that in U^{235} can be brought below the critical value.

The first nuclear reactors were constructed using graphite or heavy water as the moderating material and since heavy water absorbs fewer neutrons than graphite the heavy water reactors were smaller in size and contained less uranium than the graphite reactors.

A practical reactor must produce large quantities of heat and this heat must be extracted in a safe manner. This requires the introduction of a circulating material to remove the heat and suitable containers to avoid chemical reactions between this coolant and the uranium and graphite. The uranium must also be separated from the coolant so that the fission products, which are highly radioactive, are not trapped in the coolant and deposited in heat exchangers and pumps outside the reactor. The coolants and containers must again be chosen to capture as few neutrons as possible. Possible coolants are gases, e.g. air, CO_2, He, N_2 and liquids, e.g. D_2O, H_2O and a variety of organic coolants and liquid metals such as Na, Pb, Bi. Possible containers are e.g. Al, Mg, Zr.

The intense radiation arising from the large number of nuclear reactions occuring inside a reactor requires that a shield should surround the reactor. This shield must absorb these radiations and dissipate their energy. The usual principle of design is to use hydrogeneous materials to slow down the fast neutrons, other materials, e.g. boron, to absorb thermal neutrons without releasing penetrating radiations, and heavy elements to absorb the gamma radiation.

A typical balance sheet for the neutrons in a natural uranium graphite moderated reactor is given in Table II. The coolant is water and the containing tubes are made of aluminium. The reactor core is about a 25 ft. cube and contains about 100 tons of uranium with a heat output of about 400 MW. As a result of the large number of fissions taking place a large number of fission products are formed and these will also absorb neutrons.

TABLE II

Neutron Yield		*Neutron Absorption*		*Neutron Leakage*	
U^{235}	2·05	U^{235}	1.00		0·04
U^{238}	0·06	U^{238}	0·80		
		Graphite	0·15		
		Water	0·05		
		Aluminium	0·04		
		Fission Products	0·03		
Total	2·11	Total	2·07	Total	0·04

OTHER REACTORS

Obviously, if the relative amounts of U^{235} and U^{238} can be changed, additional flexibility in design is possible. Table III gives a typical selection of figures for various reactors.

An alternative type of reactor would use a mixture of fuel and moderator ; this is known as a homogeneous reactor in contrast to the heterogeneous reactor which requires the fuel to be in lumps. Here again considerable reduction in the U^{238}/U^{235} ratio is required.

When a nuclear reactor has been operating for some time at power noticeable changes will occur in the composition of the fuel. Table IV lists the main events for uranium and thorium.

A proper consideration of the long term characteristics of reactors will therefore include a consideration of all the processes shown above in addition to the complications of the production of fission products.

FUEL UTILIZATION

It is of considerable importance in the long run that the nuclear fuels, like other fuels, should be utilized to the full, although their initial utilization may be quite small.

TABLE IV

Element	*Comments*	*Element*	*Comments*
U^{238}	Fissile (MeV) Neutron Capture	Th^{232}	Fissile (MeV) Neutron Capture
U^{239}	Decays $T\frac{1}{2}=23$ mins.	Th^{233}	Decays $T\frac{1}{2}=23$ mins.
Np^{239}	Decays $T\frac{1}{2}=2{\cdot}3$ days	Pa^{233}	Decays $T\frac{1}{2}=27$ days
Pu^{239}	*Fissile* Neutron Capture	*U^{233}*	*Fissile* Neutron Capture
Pu^{240}	Fissile (MeV) Neutron Capture	U^{234}	Fissile (MeV) Neutron Capture
Pu^{241}	*Fissile* and decays $T\frac{1}{2}=14$ yrs. Neutron Capture	*U^{235}*	*Fissile* Neutron Capture
Pu^{242}	— Neutron Capture	U^{236}	Fissile (MeV) Neutron Capture
Pu^{243}	Decays $T\frac{1}{2}=5$ hrs.	U^{237}	Decays $T\frac{1}{2}=6{\cdot}7$ days
Am^{243}	Long lived $T\frac{1}{2}=10^4$ yrs.	Np^{237}	Long lived $T\frac{1}{2}=2\times10^6$ yrs.

The two basic nuclear fuels for the fission process are uranium and thorium. As has been demonstrated a nuclear reactor can be constructed with naturally occurring uranium but thorium^{232} is rather like uranium^{238} in that it requires a certain amount of fissile material before the reaction will occur. Such fissile material must be provided by man. However, almost complete ulitization of uranium and thorium is possible as is seen from Table IV, since the amounts of material

TABLE III

Reactor	*Moderator*	*U^{238}/U^{235} atomic ratio*	*Yield*	*U^{235}*	*U^{238}*	*Moderator Absorption*	*Sheaths and Coolant Absorption*	*Sheaths and Poisons Absorption*	*Leakage*	*U tonnes*	*Cubeside of core*
Thermal	Graphite	139	2·11	1·00	0·80	0·15	0·05 (H_2O)	0·07	0·04	100	25ft.
Thermal	Heavy Water	139	2·11	1·00	0·90	0·02	negligible (D_2O)	0·05	0·14	10	8ft.
Thermal	Water	100	2·20	1·00	0·95	0·10	0·05 (H_2O)	0·05	0·05	100	8ft.
Fast*	None	5 (core) 139 (blanket)	2·7	1·0	1·3	nil	0·2(Na)	0·1	0·1	1 (core) 100 (blanket)	1½ft.

* The fast reactor core is surrounded by natural uranium which acts as a neutron reflector and also captures neutrons in U^{238} which would otherwise have leaked out of the system.

produced which cannot be fissioned eventually is very small.

An important parameter in the consideration of fuel utilization is that of conversion factor C defined as the ratio.

$$C = \frac{\textit{Production of fissile material}}{\textit{Loss of fissile material}}$$

It is clear already that any nuclear reactor contains fissile material and if $C = 1$ then the nuclear reaction will continue so long as fertile material is supplied to it. The fertile material is of course the source of new fissile material. In this way all the basic fuel can be utilized. In practice, of course, there would be losses associated with chemical and metallurgical processing and so it would be desirable for C to be greater than unity. There is, however, another incentive for C to be greater than unity since one of the nuclear fuels, thorium, requires additional fissile material to start a reaction and since greater freedom of design is possible with uranium if additional fissile material is available. It is important, however, to realize that even if C is less than unity a certain utilization of the fuel can be achieved.

In fact the reaction will proceed such that the total atoms destroyed will be

$$1 + C + C^2 + \ldots . C^n = \frac{1 - C^{n+1}}{1 - C} \text{ times the}$$

fraction of original fissile atoms destroyed; where n is the ratio fertile to fissile atoms. For example with a natural uranium feed to the reactor quantities of plutonium are produced which will help to keep the reactor going and if all the U^{235} can be destroyed

then approximately $\frac{100\ (1 - C^{140})}{140\ (1 - C)}\%$ of the

uranium will be destroyed. Table V gives typical values, although not quite all the uranium destroyed is fissioned.

TABLE V

C	% *destruction of uranium*
0·70	2·4
0·80	3·6
0·90	7·1
0·95	14·3
1·00	100·0

Now we can see from equation (3) that C can be made large for large values of $\gamma - 1$. We must consider therefore the yields of the various fissile materials as a function of energy to see which system is likely to offer the best chance of a high value of C. Table VI lists the relevant data.

TABLE VI

	Thermal	*Intermediate*	*Fast*
U^{235}	2·0	1·8	2·4
Pu^{239}	2·0	1·8	2·8
Pu^{241}	2·2	?	?
U^{233}	2·3	2·3	2·4

In considering this table we should remember that a feed of natural uranium will involve the yields from U^{235}, Pu^{239} and Pu^{241} and a feed of thorium will involve the yields from U^{233} and U^{235}. However, it can be said that a fast reactor seems to offer the best chance of a large value of C for a feed of natural uranium but there is little to choose between the reactors on this basis for a feed of thorium.

ECONOMICS OF NUCLEAR POWER PRODUCTION

The economics of the production of electricity from nuclear power stations can be considered in the same way as those of conventional power stations. Two factors are important.

(i) Capital investment
(ii) Cost per kWh electricity produced.

The capital investment can be considered as composed of three factors :

(i) Cost of reactor and coolant circuit
(ii) Cost of conventional generating equipment
(iii) Cost of initial fuel loading.

The cost per kWh can be considered as composed of three factors :

(i) Interest and depreciation rate on the capital investment
(ii) Operating costs
(iii) Fuel consumption.

It is convenient to introduce symbols for a number of important parameters; the operating charges are not considered as it is not expected that they will differ much from conventional stations.

The relative importance of load factor, thermal efficiency, fuel rating, cost and utilization, and processing costs can be determined from these formulae although care is necessary in deducing marginal conclusions since the detailed inter-relation of the parameters is not taken into account. For example a high rating may require a more expensive fabrication process and so on. However, such conclusions as " high fuel cost requires a high rate of heat extraction from the fuel and high utilization " are obviously correct.

Fuel reprocessing costs appear for two reasons. Bombardment of materials by neutrons and gamma radiation results in damage due to the displacement of nuclei

K_R cost in £ per kW (Heat) of the reactor and coolant circuit
K_G cost in £ per kW (Electricity) of the conventional generating equipment
I cost in £ per kg of the initial fabricated fuel
U cost in £ per kg of the fuel used as feed to the reactor subsequently
P_m cost in £ per kg of the metallurgical fabrication of fuel
P_c cost in £ per kg of the chemical reprocessing of fuel
N number of times the fuel is passed through the reactor
R heat rating of the fuel in kW (Heat) per kg of fuel
p percentage of fuel fissioned in one pass through the reactor
α net percentage efficiency of conversion from thermal to electrical energy
β interest rate charged on the fuel, per cent per annum
γ percentage load factor for the station
δ_R interest and depreciation rate on the reactor and coolant circuit, per cent per annum
δ_G interest and depreciation rate on the conventional generating equipment, per cent per annum

Then the total capital investment is

$$\frac{100K_R}{\alpha} + K_G + \frac{100I}{\alpha_R} \text{ in £ per kW (Electricity)} \quad \ldots \quad (5)$$

representing the reactor, generating and fuel costs respectively.

The cost per kWh breaks down into the following items in pence per kWh.

$\frac{2{\cdot}74\, K_R\, \delta_R}{\alpha\gamma}$ reactor capital investment

$\frac{0{\cdot}0274\, K_G\, \delta_G}{\gamma}$ conventional generating equipment capital investment

$\frac{2{\cdot}74\, \beta\, I}{R\alpha\gamma}$ fuel capital investment

$\frac{0{\cdot}10\, U}{\alpha N p}$ fuel consumption

$\frac{0{\cdot}10\, P_m}{\alpha p}$ fuel fabrication

$\frac{0{\cdot}10\, P_c}{\alpha p}\left(\frac{N-1}{N}\right)$ fuel reprocessing

$$\text{i.e. } \frac{2{\cdot}74}{\gamma}\left[\frac{K_R\,\delta_R}{\alpha}+\frac{K_G\,\delta_G}{100}+\frac{I\beta}{R\alpha}\right]+\frac{0{\cdot}10}{\alpha\rho}\left[\frac{U}{N}+P_m+P_c\,\frac{(N-1)}{N}\right] \quad \ldots \quad \ldots \quad (6)$$

from their lattice positions and chemical effects may arise due to the displacement of electrons. It may be necessary therefore to remove fuel from the reactor in order that these effects can be ameliorated. Furthermore as has already been indicated the changes in the neutron balance due to the changes in the composition of the fuel and the production of fission products may cause the reaction to stop.

Consider first a reactor in which $N=1$, i.e. after the fuel has been removed from the reactor it is treated as of no value. In practice, of course, it will have a certain credit or debit allowance depending on circumstances and this will be discussed later. Typical figures[1] are given in Table VII which are estimates for the first Nuclear Power Stations to be constructed for the Central Electricity Authority.

TABLE VII

Item	*Cost per unit pence*
Reactor Capital Investment	0·16
Fuel Capital Investment	0·05
Other Capital Investment	0·16
Fuel Consumption ($\frac{1}{3}$% utilization)	0·33
Operating Charges	0·06
Total Cost	0·76

These figures are to be compared with those for conventional stations which are given in Table VIII for the same load factor.

TABLE VIII

Item	*Cost per unit pence*
Total Capital Investment	0·16
Fuel Consumption Charges	0·38
Operating Charges	0·06
Total Cost	0·60

It can be seen, therefore, that with a very modest utilization of uranium generating costs are not much higher than for conventional stations. However, it is possible to argue that a certain credit allowance should be made for the fuel passed once through the reactor in this way. It is certainly possible to remove the fission products and extract the plutonium which can then be used to fuel new reactors. Alternatively it could be fed back into the reactor from which it came. However, as we have seen, fissile material is at a premium in the initial stages of a reactor programme at any rate and it may therefore be more advantageous not to return it to its original reactor. Estimates of the credit allowance which it is believed can be given for this material are quoted in Table IX[1].

TABLE IX

Purpose of Pu	*Price £ per gm.*
To fission to produce heat	3 to 6
To mix with natural uranium or thorium to fuel a new reactor	12

This credit allowance introduces another term into the cost per kWh. This extra term may arise in another way. If we are operating a reactor system in which the conversion factor C is greater than unity, as appears likely in some systems, then the reactor can be maintained in operation without using all the fissile material produced from fertile material. In this case the obvious move is to use this to increase the number of reactors requiring man made fissile material and appropriate credit must be allowed.

Let F be the allowance in £ per kg for the irradiated fuel discharged from the reactor after one pass through the reactor. Then the credit allowance to the cost per kWh is $\dfrac{0{\cdot}10\,F}{\alpha\rho}$.

For a single pass of fuel through the reactor $I=U$ and then

cost per kWh. =

$$\frac{2{\cdot}74}{\gamma}\left[\frac{K_R\,\delta_R}{\alpha}+\frac{K_G\,\delta_G}{100}+\frac{U\beta}{R\alpha}\right]+\frac{0{\cdot}10}{\alpha\rho}\left[U+P_m-F\right] \quad \ldots (7)$$

The effect of this is shown in Table X.

TABLE X

Item	*Cost per Unit pence*
From Table VIII	0·76
Credit for Pu at £5 per gm. before processing, i.e. F ~ £10	−0·17
Net Cost	0·59

For a reactor system with C greater than unity we may imagine that the initial investment consists of fissile material F and fertile material U in the proportion m grams of fissile material to one kg of fertile material. The fertile material will then be completely utilized, neglecting losses in processing, i.e. $N = \frac{100}{p}$ and credit can be given for the excess fissile material produced. The cost per unit is then

$$\text{Cost/ kWh} = \frac{2{\cdot}74}{\gamma}\left[\frac{K_R\,\delta_R}{a} + \frac{K_G\,\delta_G}{100} + \frac{(0{\cdot}010mF + U + P_m)\,\beta}{Ra}\right] + \frac{0{\cdot}10}{a}\left[\frac{U}{100} + \frac{P_m}{p} + P_c\,(1 - p/100) - \frac{F\,(C-1)}{100}\right] \quad \ldots\ \ldots\ \ldots \quad (8)$$

where C is the conversion factor ; $\frac{R}{m}$ is now the rating of the fissile material in kW per gm.

Providing that F remains constant with time we see that the cost per kWh will be independent of the cost of fissile material if

$$\frac{0{\cdot}0274\,mF\,\beta}{Ra\gamma} = \frac{F}{1000}\,\frac{(C-1)}{a}$$

$$\text{i.e. } C - 1 = \frac{27{\cdot}4\,m\beta}{R\gamma}$$

A typical value for β/γ might be 1/20 for a base load station. Then $C - 1 = \frac{1{\cdot}37\,m.}{R}$

It is therefore possible, by having a sufficiently high rating and a conversion factor sufficiently in excess of unity, to reduce the importance of the cost of man-made fissile material.

DEVELOPMENT OF NUCLEAR POWER STATIONS

The preceeding discussion has brought out the importance of the various factors involved in the theoretical economics of nuclear power stations. It is reasonable to suppose that the development should proceed along the following lines.

(i) Use of natural uranium as fuel while it is still cheap and relatively abundant. The utilization may be small but man-made fissile material will also be produced and the cost per kWh should be close to that of conventional stations. These stations will necessarily be large since large amounts of fuel or heavy water are needed.

(ii) Gain engineering experience in constructing and operating nuclear power stations using natural uranium in a thermal reactor. Some experience is available already with such reactors, although most of these have been built for different purposes, e.g. production of fissile material for military use or as a machine for producing large numbers of neutrons.

(iii) Make use of man-made fissile material to initiate reactors with a more flexible design in order to improve the utilization of uranium, utilize thorium and cover a wide range in installed capacity.

A programme of this kind is envisaged in the White Paper[2] published in 1955 which considers in outline the design, construction and operation of natural uranium reactors and reactors containing small amounts of additional fissile material for central electricity generation in the period 1955-1965.

SUMMARY OF OUTSTANDING PROBLEMS

The objectives in the development of economic nuclear power can be stated simply :

1. Cheap construction, since capital costs are necessarily larger than for conventional stations.

2. Reliability in operation, since high load factor is essential initially.

3. Flexibility in design to achieve wider range of output and high fuel utilization, the former so that the application of nuclear power can be extended and the latter as insurance against an increased demand for nuclear fuels and to offset the cost of man-made fissile materials.

In order to achieve these objectives many branches of science must contribute to research and development and in conclusion a few of the important factors are discussed briefly.

(*i*) *Effects of Irradiation on Materials.*

This field is probably the most important one at the present time since the choice of suitable materials will affect the capital cost, the lifetime and the reliability of the reactor. Very considerable technological effort is required to define methods of using materials which will maintain satisfactory properties under the extreme condition of neutron and gamma radiations existing in a reactor. The problem is made more difficult by the requirement that all materials other than fissile and fertile materials should absorb the minimum number of neutrons. This requirement has led to the development and use of completely new materials on a large scale, e.g. heavy water, pure graphite, beryllium, zirconium, etc.

The availability of intense sources of neutron and gamma radiation has, of course, provided a new tool with which to investigate the fundamental properties of the structure of the solid state and of the factors governing chemical reactions.

(*ii*) *Properties of Nuclear Radiations*

The design of the reacting cores, the shields and the specification of control devices for nuclear reactors requires a very detailed knowledge of the interaction of neutron and gamma radiation with matter. In addition to the accumulation of the basic data regarding these processes, a large programme of applied research is necessary in order to produce satisfactory design formulae. The accuracy of fundamental measurements alone is not sufficient for this purpose, since for example an error of 1 or 2% in the determination of the yield of neutrons from fissile material can lead to a change of the critical mass of a factor of two in a typical natural uranium graphite moderated power reactor.

(*iii*) *Heat Removal*

The problem of economic heat removal from nuclear reactors is complicated by the limitations on materials and the form of the heat generating element which the neutron balance imposes. The high rates of heat production per unit volume found necessary in fast reactors set new problems and the technological development of the use of liquid metals is thought necessary.

It is clear that only by combining the results of fundamental research, technological development and engineering experience in design, construction and operation will economic nuclear power contribute significantly to world power resources. Nevertheless such a contribution will be required in the near future and in Great Britain the Government has announced in a White Paper[2] the provisional plans for the building of twelve nuclear power stations, probably comprising sixteen reactors. These are in addition to the eight production reactors being constructed by the Atomic Energy Authority which will also generate substantial amounts of electricity. The first of these is expected to be in operation by the end of 1956.

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Vol. 7, August, 1956

Sandwich Diploma Courses*

By

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THE SUBJECT of Sandwich Courses has been discussed frequently and at great length in recent years. Most people are aware of the nature of these courses but in order to ensure that we are all thinking about the same thing I must run the risk of boring you by explaining briefly what the name implies as far as this talk is concerned. In Sandwich Courses students spend alternate periods in college and in employment over a number of years. The name is usually restricted to courses in which the periods are roughly equal, say six months in full-time study with six months in industry during each year for a number of years. Such courses are not new. They have been in operation in some universities and colleges for many years. However, recently they have been put forward afresh as a type of course well suited to the training of industrial technologists and they are being offered by most of the larger technical colleges to-day. The courses are, to some extent, a compromise between the part-time day-release course and a full-time course. It is claimed that they have some of the advantages without the disadvantages of both of these types of course. The periods of six months in college give opportunity for concentrated study, and yet each year there is ample time in industry to acquire practical experience. The two types of experience are gained concurrently during the period of training and can have a beneficial leavening upon each other.

This afternoon we are due to discuss Sandwich Diploma Courses. I am not sure if I am supposed to discuss these primarily in terms of courses in physics. Most of the major problems and issues are common to all sandwich courses and I propose to review some of these general problems without attempt at specialization. It should be emphasized that these remarks are based on rather limited experience at Birmingham where Sandwich courses are now in their second session.

ENTRANCE QUALIFICATIONS, DURATION AND STANDARDS

I should like to deal with these items together as they are closely inter-related. Firstly, however, it is necessary to settle the nature of the end product of the scheme. I think it is usual to-day to consider that the man coming through a sandwich course should ultimately qualify as a professional technologist and his sandwich training should therefore satisfy the educational requirements for graduateship of a professional institution, i.e. he should reach the standard of a good university degree. If he studies for six months per year and commences with normal university entrance qualifications it would therefore take about four years to reach the required standard. Some people argue that the experience in industry will assist in the appreciation and assimilation of academic knowledge to such an extent that the required standard could be reached in three years. On the other hand, many say that five years would be needed to reach good honours degree standard. This appears to be the view of some of the officials in the Ministry of Education. Four years would appear to be a reasonable compromise.

* A lecture given to the Education Group of the Institute on April 5, 1956.

It has been assumed above that the entrance requirements for sandwich courses would be the same as for a University. It is feared by many people that there will not be enough school leavers reaching that standard to fill both the university and the technical college courses. There may be some truth in this, but it is part of a greater national problem of finding enough technologists to run a community which becomes rapidly more and more dependent on technology. It may be that there will have to be considerable diversion of school leavers into the technology streams of both universities and technical colleges. In any case it is true to-day that there are many recruits to industry straight from the grammar school sixth forms. These are people who, for one reason or another, do not go to a university and in the past have taken technical college courses on a part-time day-release basis. The sandwich scheme would provide a much better type of training. In some colleges less than university entrance standard is accepted for sandwich courses. There may be a case for taking people with good sixth form records in mathematics and science even though they do not satisfy all the other requirements. Most colleges are accepting selected students from ordinary National Certificate courses. It is pleasing to note that these people are so far showing up quite favourably in comparison with the sixth form Grammar School recruits.

Some colleges are prepared to accept even lower standards of entrance in order to get courses started, but it is to be hoped that there will be some measure of agreement amongst the colleges on minimum entrance standards.

AWARDS

But for the problem of getting agreement with all concerned on the controversial subject of a suitable award for technical college students, the country might have had its new deal for technical education long ago. The standard for our sandwich courses has been agreed as that of a good university degree and it might appear that the obvious award is a degree in technology. For a variety of reasons this is not to be, and there would be no point in raising again all the many arguments for and against a B.Tech. Some colleges, with a fair measure of support from industry, have felt that, as they cannot award their own degree, they should prepare students during their sandwich courses for the external degrees of the University of London. The main argument in favour, and a very powerful one it is, is the undoubted status given by the magic letters "B.Sc." A second strong argument in favour of the external degree is that it ensures an adequate standard. Even so, I feel personally that the adoption of the external degree as the main award for sandwich students would be most unwise. Preparing students to take an external examination is not necessarily the same thing as training them to be good technologists. The syllabuses of the external degrees have not been drawn up with the technological needs of industry in mind. Indeed it would be true to say that the General Degree, which has been the main objective of most Technical College science courses in the past, has been far from an adequate training for industrial technologists. I am not suggesting of course that sandwich students should be given a highly vocational training—far from it. The objective should be to cover those basic principles which will have to be the scientific stock-in-trade for our technologists for the forty years or so of their life in industry. However, basic principles can be taught with a modern and applied outlook without necessarily becoming any less basic. It may even be possible to cover some of these principles in relation to the local interests of students though I would not like to make too much of this point. However, if this sort of outlook is to be maintained it is not at all desirable that the teacher should at the same time have constantly in mind an external examination which will be set and marked by someone who is unaware of the outlook and may not even be sympathetic towards it. It is for these reasons that I suggest that the colleges should not work towards external degrees. In passing I must point out that I am not

belittling the important and valuable part that has been played in the past by the London external degree particularly in setting a standard for technical college courses.

What then is to be the award for students who complete our Sandwich Courses sucessfully ? At the moment it appears that the only award available is a College Diploma or Associateship. Unfortunately, in the past these have been awarded for courses which have often fallen far short of the standard which we are setting now. In this connection the Diploma is particularly unfortunate though its adoption seems to be implied in the title given to this talk. Higher National Diploma courses have been in operation in various colleges for many years. In most cases they have been poorly supported and the students have all too often been people incapable of gaining University entrance. In addition the nature and standard of these courses is quite different from what we are contemplating for sandwich courses and it would be a pity to get the latter debased by adopting the Diploma Award. It may seem that I am labouring this point somewhat but I know that some colleges are offering sandwich courses which are little different from their Higher National Diploma courses.

It may be that when the Hives' Council gets busy and awards its Diploma in Technology to technical college courses of approved standard, the problem of a suitable award for sandwich courses will disappear. That remains to be seen. In the meantime this question remains a major problem since neither students nor industrialists will be keen to give full support to courses which do not guarantee an award of professional standard on completion. Here the professional institutions can play an important part by giving recognition for graduate membership purposes to sandwich courses in selected colleges where standards of staff, accommodation, equipment, etc., are known to be sufficiently high. At the same time it is essential that this recognition should be given with great care and should be used as a means of raising standards to the necessary level. The Institute of Physics has made a good start here and has given such recognition to five colleges. One or two other professional institutions are also adopting this policy.

On this question of awards it must be emphasized that the Colleges themselves have an all-important and positive part to play in influencing future policy. They must not look on sandwich courses merely as a means of providing greater numbers of full time students and a Diploma in Technology as a convenient token of status and respectability. Status can only be achieved by internal efforts and it is most unlikely that the professional institutions or the Hives' Council will give recognition to sandwich courses in more than a few colleges. In passing I would say that the selection of 24 colleges for upgrading and for a share of £75,000,000 is not very realistic. There are just not enough staff of the right calibre to justify upgrading this number.

INDUSTRY AND SANDWICH COURSES

The sandwich courses to which I have already referred and which have been in operation in certain establishments for many years have been, in the main, college-based. The responsibility for finding employment during the period of the year when there were no classes rested with the student, sometimes with assistance from the college. Most of the new courses which are being initiated now are industry-based. The students are employees of a particular firm throughout the whole course. This profoundly affects the nature of the course since the employer is a major partner in the scheme. Not only does he have the normal financial responsibilities of an employer during the periods in industry, but frequently he also pays full wages during the periods in college. In addition, during half of the training the student is in industry and so the employer can exert considerable influence. I have been surprised and most encouraged by the interest and breadth of outlook shown by many industrialists, particularly in the larger firms. Even though the scheme is a most costly one—it may amount to about £1,000

per student—many employers are really interested and they want to take an active part in the development. The colleges should welcome this co-operation openly. I know that the amateur educationist can be a bit of a menace, but unless the colleges can bring the employers into full partnership, the sandwich scheme will lose one of its major attractions if it does not lose the employers' support altogether. The periods in industry are as important in the development of the student as the periods in college, and they should be just as carefully planned. Employers will expect some guidance or co-operation from the colleges in planning the practical training and the colleges must be prepared to face up to this. At the same time the firms should be encouraged to take an interest in the activities of their apprentices during the college period.

Here I would like to suggest that these industry-based sandwich courses are still very much in the experimental stage. The colleges should not be afraid to admit this and to seek advice and opinions from their industrial partners in the experiment. I have noted in dealing with some of the larger firms that the main enthusiasm for sandwich courses comes from the development and production departments. Research departments on the whole have shown less interest. I am not sure of the reason for this. It may be that the research people feel that they would prefer university graduates. Possibly, if the colleges had more openly admitted the experimental nature of the sandwich schemes the industrial research people would have shown more interest. Again, it may be salutary to remember that at the end of an experiment one always gets some sort of result, even though it is negative. The sandwich scheme will stand or fall by that result. In a year or two we shall be getting the first end products. They will have to be good at £1,000 a time.

The colleges must never forget the considerable administrative difficulties that sandwich courses may bring to industry. One major problem arises in accommodating students for six months of the year only. In day-release classes industry can usually arrange some levelling of the load, but when a firm has say 50 sandwich students then accommodation becomes a major problem. In order to ease this problem and at the same time to give a uniform load in the colleges, a staggered arrangement of the students in three equal groups as shown in the diagram may be used.

O N D J F M A M J J A S

One group has a continuous period of six months from October to March in college. A second group does from January to June. The third group does two three month periods, October to December and April to June. This gives a uniform load in the College from October to June, and no students from July to September. In industry there is always one group from October to June. All three groups are in industry from July to September but as these are holiday months industry may be able to accommodate them.

NUMBER OF HOURS' INSTRUCTION PER WEEK

I would like to make one point more, and this is in connection with the duration of the course. In practically every case that I have come across the technical college sandwich courses have been planned in detail for about thirty hours per week. This means three hour sessions, morning and afternoon, for five days per week. There is a tendency in technical colleges to feel that as much as possible should be included in the formal instruction. This is a natural tendency in places which have been dealing mainly with part-time students where the amount of time has to be used fully and efficiently to cover a bare minimum. The much longer time available in sandwich courses gives more freedom, and some of this time should be available for students to think as well as to listen—yes, even though they do not think physics all the time.

CONCLUSION

My remarks have been somewhat disjointed. I have tried to draw attention to

some of the major problems which I have encountered in discussing sandwich courses with industrialists. In not dealing with physics courses at all I may have failed the good intentions of the committee.

In conclusion, I would like to say that although I am no longer directly concerned with sandwich courses in technical colleges I feel quite strongly that they may have a most important part to play in the future development of technology in this country provided adequate precautions are taken to ensure high standards, mainly by limiting the technological courses to the few colleges capable of doing justice to them. At the very least one may say that sandwich courses are a most interesting experiment deserving of full co-operation from everyone interested in industrial prosperity, and that, of course, means the entire community.

Reviews of Books

AUTOMATIC DIGITAL COMPUTERS

By M. V. Wilkes, F.R.S.

London : Methuen & Co. Ltd., 1956. Pp. 305 + x. Price 42s.

The author of this book has for more than ten years been the Director of the Cambridge University Mathematical Laboratory and so writes with considerable authority about automatic digital calculating machines. Primarily this is a computing-laboratory text book, its main appeal being to those who are either working in such a laboratory or who contemplate building or buying a digital computer. At the same time there is much for the reader who has only a general interest in automatic calculating machines, though he will very likely wish to skip some of the more detailed sections.

The first chapter opens with an account of the work of Charles Babbage who, over a hundred years ago, had ideas for an automatic calculating machine. This account is made very interesting by the inclusion of several personal details and anecdotes. The present era of automatic calculating machines opened with the construction of the Automatic Sequence Controlled Calculator at Harvard in 1944 and the description of this machine is followed by those of the ENIAC and EDVAC to illustrate the trend of modern developments. Much of what follows later in the book is based, not unnaturally, on the author's own machine, EDSAC. There is first the consideration of the principles of logical design, that is of the units which handle the basic processes of arithmetic and the orders which are fed to the machine. In the chapter on programme construction the reader is introduced to the important task of drawing up programmes of orders which the machine subsequently has to execute in order to handle a problem. Emphasis is placed on the preparation and use of sub-routines, separately prepared sets of orders for commonly-occuring processes, such as the extraction of square-roots, which can be taken, possibly from a library, and incorporated into a main programme as a self-contained loop. The chapter on computers in which telephone relays are used as switching and storage elements includes a comparison of their advantages and disadvantages compared with electronic gear. A very readable account of various types of store, in which numbers and orders are kept until wanted, includes descriptions of both liquid and solid ultrasonic delay tubes, electrostatic, magnetic drum and tape, and static-magnetic storage systems. Electronic switching and computing circuits are described with the help of symbolic notation, both that of Boolean algebra which stems from symbolic logic and the more recent Harvard system in which manipulation follows the rules of ordinary algebra. The

rest of the book is devoted to a discussion of the factors which influence the design of automatic machines. There is a section on the vital question of faults, their possible causes and ways of tracing them. The author's general thoughts on the efficient organization of a computing centre are particularly valuable as they carry the weight of personal experience. The topic of machines and intelligence is fittingly relegated to an appendix.

There is so much information in this compact book that perhaps it is unreasonable to ask for more. Nevertheless the reviewer would have liked to see a fairly detailed account of how one or two typical problems have been handled on EDSAC, for example. This, probably more than anything else, would help the general reader to visualize the potential usefulness of automatic calculation machines. Dr. Wilkes' book can be recommended to the rapidly increasing number of people who are becoming concerned with high-speed calculation in one form or another.

J. CRANK.

THERMODYNAMICS AND STATISTICAL MECHANICS

By Arnold Sommerfeld.

New York : Academic Books Inc. Pp. 401 + *xviii. Price* $7.

The present work forms the fifth volume of Sommerfeld's series of lectures on theoretical physics. It has been edited by F. Bopp and J. Meizner, and translated by J. Kestin. The editors had the difficult responsibility of writing the whole of the fifth chapter from clues given only in the remarks in the author's preface to the volume. They have carried out their task exceedingly well, the style and matter of the chapter being completely consistent with the rest of the book. This is only in part due to the fact that much of it is taken up by the electron theory of metals which has been based on the article by Sommerfeld and Bethe in the *Handbuch der Physiik*. The treatment throughout the book is classical, not only in the sense that it deals mainly with what is called classical physics, although quantum theory is introduced where necessary, but also in the sense of its approach and style.

Many physicists of less stature than Sommerfeld tend nowadays to look askance at the " heat engine " approach to thermodynamics. It is pleasing to find that Sommerfeld is free from this affectation. He appears to have clearly in mind a view that the two processes of (*a*) deduction and build up of a science from the smallest possible number of axioms, and (*b*) the use of concepts derived from phenomenological experience, should be *both* part of the stock-in-trade of the physicist, being complementary and mutually stimulating.

Thus in discussing the basic laws of thermodynamics, Sommerfeld moves easily and with a complete sense of unity between the abstract approach of Caratheodory and the Carnot/Kelvin/Clausius line of development. The presentation of ideas is always clear, sometimes provocative, and usually convincing. An example of the technique of being provocative in order to be illuminating is when he emphasizes the not appreciably recognized fact that the energy content of the air in a room of a house is not dependent on its temperature, but on the barometer.

In the treatment of radiation and of statistical mechanics the author has seen fit to give a full account of classical radiation theory, and of Boltzmann and Maxwell's original approaches to statistical ideas, before introducing quantum considerations. This procedure should render the book of considerable value to students and teachers. There is so much that is brilliant and exemplary, in the classical thermodynamics of radiation, and in classical statistics, and to this brilliance Sommerfeld gives full justice, including some interesting biographical notes from the writings of Boltzmann. Indeed in regard to statistical mechanics the author's mental attitude referred to above is carried forward in the comparable unity with which he handles statistical and thermodynamic concepts. He does not merely leave the reader to assume that extensive mathematical treatment from atomistic assumptions has been done to derive phenomenological consequences. At

each completed derivation he comments adequately on the relations between the two fields. For these reasons the discussion of Bose-Einstein and of Fermi-Dirac statistics is exceedingly clear, and derives much of its clarity from being shown in relation to classical statistics.

There is a valuable concluding section with eight pages of interesting and stimulating problems, followed by some forty pages of hints for their solution, wherein the setting out of the arguments is admirable.

It is to be hoped that the book will be fully welcomed as an excellent contribution to thermodynamics teaching, and as a useful reference to basic thermodynamics for workers in other fields.

It is an unfortunate but minor blemish that the little known unit "kilopond" abbreviated kp, is used for the kilogram weight.

R. S. SILVER

INTRODUCTION TO ATOMIC PHYSICS (4th Edition, 1956)

By Professor S. Tolansky, F.R.S.

London; Longman, Green & Co. Pp. 435 + xiv. Price 25s.

This is the 4th Edition of Professor Tolansky's well known book, which is now a standard work for students in their earlier years of university study. There are four new chapters on detection of single particles, mesons, high energy particle accelerators and nuclear reactors. The first of these is perhaps too elementary but the remaining three new chapters are excellent surveys of their respective fields. It is extremely difficult to summarize the elementary theory and the technical details of several types of accelerator in the space of 23 pages, yet this has been done with only a few trivial omissions (for example, the microtron). The chapter on nuclear reactors is of great interest and provides an excellent students' survey ; there are short sections of research uses of reactors. The brief chapters on mesons is even better, as it needs to be, because of the complexity (frightening to non-nuclear physicists) of the situation.

The other chapters, so well known now to several generations of physics students since the first edition of the book appeared in 1942, may be briefly enumerated. There are chapters dealing with gaseous conduction of electricity, properties of the electron and of positive ions, electron physics (thermionics, photo-electricity, X-rays and crystal structure and collision processes in gases, etc.). There is a group of chapters devoted to nuclear physics (α, β and γ rays, cosmic rays, etc.) and chapters on quantum theory and wave mechanics.

It would almost be impertinent to recommend this book, now so well proved, as introductory work for students reading physics or for those studying for medical or engineering degrees. Perhaps its use in the latter field could, with advantage, be wider.

The price is reasonable and the technical production of the book is good.

J. D. CRAGGS.

ROBERT HOOKE

By Margaret 'Espinasse

London: William Heinemann. Pp. 192 + vii. Price 21s.

This book is not limited to the biography of a single name in the history of physics. It is an account of the late 17th Century scientific background, and the clashes of personality which in those days were too often a determining factor in research. The long antagonism between Newton and Hooke is here discussed, uncoloured by reverence for Newton which has often made it difficult to realize that he was a man with the human frailties of his time. The earliest history of the Royal Society and its connection with Gresham College, the status of Wren, Halley, Oldenberg, Boyle and Charles II in a new favourable light, appear as background to the very appealing and sometimes pathetic character of Hooke ; it seems almost incidental that Hooke's own prolific and widely scattered investigations are detailed. There is not so much about the European background, which would have made the book over heavy but even more interesting. For instance Leibniz and Leeu-

wenhoek have brief mention, and Spinoza whose correspondence with the first Secretary of the Royal Society is such a light on contemporary thought, is not mentioned at all.

The plan and execution of the book seem a model of how to present scientific history without merely biographical or merely scientific.

MARTIN JOHNSON.

The Register

ELECTIONS TO MEMBERSHIP

THE FOLLOWING ELECTIONS WERE MADE BY THE BOARD ON JULY 17, 1956

An asterisk (*) indicates transfer from another grade

FELLOWS

*Davies, Charles, M.Sc., Senior Lecturer in Physics, Acton Technical College.

Elliott, William Sidney, B.A., Manager, London Computer and Information Handling Laboratories, Ferranti Ltd., Manchester.

*Gipps, Graham De Visme, M.Sc., Ph.D., Assistant to General Manager, Telecommunications Co. of Australia.

*Jerrard, Harold George, B.Sc., Lecturer in Physics, University of Southampton.

*Valentine, James Moncur, B.Sc., Ph.D., Deputy Regional Physicist, Regional Physics Department, Glasgow.

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Bobin, Kenneth Joseph, B.Sc., Manager, Reactor School, Atomic Energy Research Establishment, Harwell.

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Carr, Kenneth George, B.Sc., Senior Physics Master, Queen Elizabeth Hospital, Bristol.

Carr, Winston Eric, M.Sc., Head of Science Department, South Berks College, Newbury.

Carter, John Paterson, M.Sc., Assistant Engineer, New Zealand Broadcasting Service.

Clouston, John Gannon, M.Sc., Scientific Officer, Weapons Research Establishment, Department of Supply, Australia.

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Appleby, Peter Brian, B.Sc., Physicist, British Thomson-Houston Co. Ltd., Rugby.

Bruce, Reginald, B.Sc., Assistant Lecturer, County Technical College, Staffs.

Chettleborough, Michael Beale, B.Sc., Geophysicist, British Petroleum Co. Ltd., London.

*Crisp, Ralph Severin, B.Sc., Student, University of Western Australia.

Dignum, Raymond, B.Sc., Royal Air Force.

Dodd, William Arthur, B.A., B.Sc., Assistant Lecturer, School of Technology, Ipswich.

Gosling, Harold William, B.Sc., Section Leader, De Havilland Propellers Ltd., Herts.

*Hammersley, David Anthony, B.Sc., Graduate Apprentice, The General Electric Co. Ltd., Coventry.

Hartley, John Roger, B.A., Assistant Master, Manchester Grammar School.

Harris, Neville Wreford, B.Sc., Research Laboratory, British Thomson-Houston Co. Ltd., Rugby.

Highfield, Ronald Albert, B.Sc., Senior Research Physicist, Tyre Performance, Development Division, Dunlop Rubber Co. Ltd., Birmingham.

Hill, John Saville, B.A., Research Student, Clarendon Laboratory, Oxford.

*Kennedy, Warren Leslie, M.Sc., Graduate Teaching Assistant, Purdue University, U.S.A.

Loney, Stuart Thomas, B.Sc., Research Physicist, Paint Research Association, Teddington.

Metzer, Kurt, B.A., Assistant Technical Editor, Cement and Concrete Association, London.

Morrow, Edward, B.Sc., National Service.

Morshead, Michael James, B.Sc., Assistant Master, Physics Department, Harrow County School.

Neal, John Saville, B.Sc., Industrial Probationer Assistant, British Petroleum Co. Ltd., Glamorgan.

O'Toole, Conor Patrick Joseph, B.Sc., Research Student, Physics Department, University College, Dublin.

Roberts, William Derek, B.Sc., Electronic Research Engineer, Marconi Wireless Telegraph Co. Ltd., Chelmsford.

Robertson, Glen Bradley, B.Sc., Research Student, University of Western Australia.

*Sayles, Robert Neville, B.Sc., Technical Officer, Imperial Chemical Industries Ltd., Harrogate, Yorks.

*Smith, Peter Faraday, B.Sc., Extra-Mural Research, University of London.

Smith, William Arthur, B.Sc., Research Student, University of Manchester.

*Townley, Bryan, B.Sc., Scientific Officer, U.K. Atomic Energy Authority, Lancashire.

Troup, Gordon John, B.Sc., Scientific Officer, Weapons Research Establishment, South Australia.

2 Subscribers and 6 Students were also elected.

The Institute's Journals

PRINCIPAL CONTENTS OF THE AUGUST, 1956, ISSUES

Journal of Scientific Instruments: Volume 33, No. 8

SPECIAL ARTICLE

The Physical Society's Exhibition—London, 1956. By A. J. Maddock, F.Inst.P.

The principal new devices, instruments and materials exhibited are briefly described and some of the improvements in earlier models mentioned.

PAPERS

An automatic device for fixing thick nuclear emulsion layers. By G. Thuro (*The Ruder Boskovic Institute, Zagreb, Yugoslavia*).

A simple device for fixing thick nuclear emulsion layers has been constructed ; it keeps the fixer flowing first one way and then the other through the box in which emulsion layers are kept. The flow of the fixer can be made as slow as required which is specially useful for continuous dilution of the fixer. The fixer runs from one flask, through the box, into another flask, and back, being driven by the pressure of the water mains. The direction of flow is automatically reversed by an electromagnetic switch, when the water in one of the flasks makes contact between a pair of electrodes.

Composite quarter- and half-wave plates. By Prof. W. H. J. Childs, F.Inst.P. (*Heriot-Watt College, Edinburgh*).

It is well known that, with certain limits, a quarter-wave plate may be made from two suitably oriented cellophane sheets. An attempt to construct such composite plates showed up some of their interesting peculiarities. These are discussed in the present paper, which also gives constructional details of quarter- and half-wave plates and extends the theory to include two- and three-component wave plates of any delay. General expressions are developed to cover all these cases ; in the case of triple-sheet combinations it is shown that it is possible to neutralize the rotation of axes which is unavoidable with two-component plates and to produce composite plates having all the properties of simple plates. To assist the design and assembly of composite plates, tables of constructional constants for double and triple quarter-wave plates, and triple half-wave plates are included.

A high-pressure diffusion cloud chamber in a pulsed magnetic field. By A. P. Batson, P. N. Cooper, and L. Riddiford, A.Inst.P. (*Department of Physics, University of Birmingham*).

A description is given of an 18 in. diameter high-pressure diffusion cloud chamber constructed for use with the Birmingham proton synchrotron. The associated equipment to provide a pulsed magnetic field of 13 kG at each synchrotron pulse is discussed and an account of the operation of the apparatus is given.

Calibration of the specimen tilt device of the EM-3 electron microscope. By J. A. Gard (*Chemistry Department, University of Aberdeen*).

An optical method is described for calibration of the specimen tilt device of the Metropolitan-Vickers type EM-3 electron microscope, for use in single-crystal electron diffraction.

A " hodoscoped " cosmic-ray recorder. By J. C. Barton (*University College of the West Indies, Jamaica, B.W.I.*)

A portable Geiger-Muller counter apparatus is described. It includes an eight-channel hodoscope and is designed for use at great depths. Simple transistor circuit techniques are used in conjunction with magnetic tape-recording. A discussion is given of the operation of counters from a stabilized voltage supply for greatest possible battery life. The complete

equipment consumes about 50 mW and will operate unattended from one set of batteries for longer than a month. The apparatus has been operated successfully in a coal mine at a depth of 1500 ft. below the surface.

Demagnetization of magnets due to contact with ferromagnetic bodies. By M. McCaig, F.Inst.P. (*Permanent Magnet Association, Central Research Laboratory, Sheffield, 1*).

The circumstances in which permanent magnets are partially demagnetized by repeated contacts with ferromagnetic bodies have been investigated. If a bar magnet is placed a few times on a block of mild steel and removed by a sliding motion parallel to its length, a loss of magnetization of the order 40% may occur. Over 3 mm. thickness of protective material is necessary to keep the losses below 1%.

A precision electrode-less conductance cell for use at audio-frequencies. By S. R. Gupta, and G. J. Hills (*Imperial College of Science and Technology, London, S.W.7*).

The design and performance of a transformer bridge for the measurement of the electrolytic conductivity of concentrated aqueous solutions is described. It operates at audio-frequencies and does not involve the use of electrodes. With moderately and highly conducting solutions the reproducibility of the measurements is better than 0·02%.

A mechanical-electrical transducer of simple design. By M. Manzotti (*The Medical School, University of Birmingham*).

A probe electrode plunged into a current field experiences a potential which is a function of its position in the field; when it is moved, the variation of potential is also a function of the displacement. This principle makes possible the design of mechanical-electrical transducers of simple construction and easy assemblage. An application to pressure recording is here described. The sensitivity (5 cm of water per full deflexion) and speed of response (no distortion for variations of pressure up to 220 cm of water per second) can, if necessary be easily improved.

A simple, small dielectric test cell for liquids. By S. Baxter, F.Inst.P. and P. D. Wilmot, A.Inst.P. (*Monsanto Chemicals Ltd., Ruabon, Denbighshire*).

An easily constructed guard ring test cell, which is both robust and precise, is described. Its calculated capacitance has been compared with values estimated from results using liquids of known dielectric constant and good agreement obtained.

LABORATORY AND WORKSHOP NOTES

A McLeod gauge for measuring a wide range of pressures.
By H. A. Wyllie

An automatic absolute reflectometer.
By J. H. Jaffe *and* U. Oppenheim.

A flexible mount for specimens in single crystal and powder X-ray cameras.
By E. Aruja.

A mercury cut-off for transferring gas at atmospheric pressure into a high vacuum.
By N. N. Greenwood.

Phasing device for small synchronous motors.
By D. T. R. Dighton *and* W. G. Waters.

A water-driven device for filling, aerating and agitating baths.
By A. L. Sims.

Laboratory furnace with rotating table for producing conducting glass.
By E. Alexander *and* I. T. Steinberger.

A transducer for the sequential measurement of two levels of thrust.
By J. G. Clouston

A liquid level regulator for replenishing cold traps.
By H. C. Probyn.

An easily constructed helium flow counter.
By E. J. Harris.

CORRESPONDENCE

Coulometric titrations using a pulse technique.
From M. A. V. Devanathan *and* Q. Fernando.

An improved photomultiplier construction.
From A. E. Jennings *and* C. E. F. Misso.

A cloud chamber illumination unit.
From A. Bardocz *and* A. Klatsmanyi.

British Journal of Applied Physics: Volume 7, No. 8

SPECIAL ARTICLE

Physics in oceanography. By K. F. Bowden, F.Inst.P. (*Oceanography Department, University of Liverpool*).

The physics of the oceans is a subject in which considerable progress has been made in recent years, largely because of the increasing application of new techniques. Some examples of the development or adaptation of physical methods for research at sea

are described, with some of the results they have given in problems such as those of waves, storm surges and ocean currents.

Papers

Dielectric properties of polar solutes in non-polar solvents at microwave frequencies. By D. E. Clark, A.Inst.P. and S. N. Kumar (*The Northern Polytechnic, London, N.7*).

The dielectric loss and permittivity of solutions of polar molecules in non-polar solvents have been measured at frequencies $9{\cdot}2 \times 10^9$ c/s and $3{\cdot}5 \times 10^{10}$ c/s. At the lower frequency independent determinations of absorption and wavelength were made on solutions of benzophenone over the temperature range 10 to 30° C. At the higher frequency the solute investigated was nitromethane and the temperature range was 10 to 40° C. Values of dipole moments obtained were 2·95 Debye units and $2{\cdot}85_5$ Debye units for benzophenone and nitromethane respectively.

The expansion of mercury and fused silica between 0 and 300° C. By A. H. Cook (*National Physical Laboratory, Teddington, Middlesex*).

The determinations of the thermal expansion of mercury and fused silica have been reviewed. In principle the absolute hydrostatic balancing method is a more satisfactory way of measuring the expansion of mercury than deducing it from the expansion relative to a fused silica bulb, but a discussion of the determinations shows that despite the variability of the expansion of fused silica from specimen to specimen, systematic errors affecting the absolute determinations make them less reliable than the relative measurements of Harlow and Beattie and others. It is recommended that for the most acurate work, the expansion formula given by the latter authors should be used instead of that given by Sears. The present uncertainty of the change of volume with temperature is about one or two parts in a million of the volume at 0° C. for temperatures from 0 to 300° C, and may be as much as one part in ten thousand at other temperatures.

The tension in strings wrapped slantwise round cylinders when friction is proportional to a power of the normal reaction. By C. Mack, A.Inst.P. (*British Cotton Industry Research Association, Shirley Institute, Manchester*).

It is now well established that for many, if not most, pairs of materials in contact friction is proportional to a power, smaller than unity, of the normal reaction. The relations between tension, normal reaction, curvature and certain angles are found for a string wrapped slantwise round a cylinder of general cross-section for friction obeying the law : (i) when friction acts tangentially to the string path and (ii) when it acts parallel to the cylinder axis.

Space-charge limited current in insulating oil. By Tadashi Sato, Shigeo Nagao, and Yofugo Toriyama (*Engineering Faculty, Tohoku University, Sendai, Japan*).

In order to analyse the pre-breakdown phenomena in insulating oil, a hot tungsten filament emitting an abundance of electrons in a vacuum was employed as cathode. The gap between the electrodes was therefore only partly occupied by the liquid. Currents measured with various voltages and depths of oil were explained on the basis of space-charge limitation in the oil, and the mobility of the negative ion in transformer oil formed by the attachment of electrons to oil molecules was found to be 1×10^{-4} cm/s per V/cm.

The vibration of segmented beams. By J. P. Ellington (*University of Nottingham*).

The frequency equations and normal modes are obtained for the flexural oscillations of a light beam carrying equal and equally-spaced concentrated masses. The mass distribution in the "lumped mass" approximation to a continuous beam is discussed.

Applications of a transformer analogue computer. By J. R. Barker, A.Inst.P. (*Electrical Engineering Dept., Imperial College of Science and Technology*).

The Blackburn analyser is a versatile transformer analogue computer well-known among electrical-power engineers as an a.c. network analyser. This paper shows that it can be used to solve many algebraic problems involving real or complex numbers. Among these are the extraction of the latent roots of matrices, the location of the zeros of polynomials, and the solution of linear and non-linear simultaneous equations.

Correspondence

Note on discharges from a flat thermionic cathode.

From N. R. Daly *and* K. G. Emeleus.

A photographic method of obtaining stress trajectories.

From D. Vasarhelyi ; A. R. Morris.